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DEVELOPMENT AND UTILIZATION OF A LASER VELOCIMETER SYSTEM FOR A LARGE TRANSONIC WIND TUNNEL

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SUMMARY

The need for measurements of the velocity flow field about spinner-propeller nacelle configurations at Mach numbers to 0.8 was met by a specially developed laser velocimeter system. This system which uses an argon-ion laser and 4-beam 2-color optics was required to operate in the hostile environment associated with the operation of a large transonic wind tunnel.

To overcome the conditions present in locating the sensitive optics in close proximity to the wind tunnel, an isolation system was developed. The system protects the velocimeter from the high vibrations, elevated temperatures, destructive acoustic pressures and low atmospheric pressures attendant with the operation of the wind tunnel.

The system has been utilized to map the flow field in front of, behind and in between the rotating blades of an advanced swept-blade propeller model at a Mach number of 0.8. The data collected by the system will be used to correlate and verify computer analyses of propeller-nacelle flow-fields and propeller performance.

INTRODUCTION

The increasing need for fuel efficient aircraft propulsion systems has given rise to the re-evaluation of the turbopropeller as an alternative to turbojets and fans on today's commercial aircraft (refs. 1 and 2). Computer codes of a new generation of turbopropellers indicate a possible 30 percent improvement in fuel efficiency compared to existing propulsion systems (ref. 3). A test program to verify the performance predictions (ref. 4) of 0.6 m (24 in.) diameter propeller models was initiated at the Lewis Research Center's 8x6 Foot Supersonic Wind Tunnel

The Laser Velocimeter was proposed to be used to obtain data for verification of the computer codes predicting the flow fields in and about the propeller blades. A L.V. was assembled and installed in an area removed from the wind tunnel (fig. 1) where check out and debugging were accomplished. With completion of the checkout, the system was relocated adjacent to the wind tunnel test section. Initial attempts to operate the L.V. during wind tunnel tests revealed the system's inability to function in the environment generated.

The solutions to the environmental problems and other difficulties encountered are addressed in this report.

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The L.V. system described has been used to obtain flow field data in front, behind and in between the blades of a 0.6 m (24 in.) diameter 8 blade turbo propeller model operated at a tunnel velocity of $M = 0.8$ (ref. 5).

SYSTEM DESCRIPTION

The L.V. system described is installed in the balance chamber of the Lewis 8x6 Foot Supersonic Wind Tunnel (ref. 6). The tunnel can be operated in either an open or closed cycle from speeds of $M = 0.36$ to $M = 2.0$. Power is provided by three 21.6 MW (29 000 hp) electric motors. The balance chamber, a large domed structure, surrounds the test section and operates at tunnel static pressures. Optical access to the model is provided by a 0.67 m (26 1/2 in.) diameter Schlieren quality window in the tunnel side wall. The propeller model tested (fig. 2) is mounted on the approximate centerline of this window.

The L.V. was raised to the test section elevation by a structural steel stand (fig. 3) mounted to the floor in the lower level of the balance chamber. This stand is approximately 4.27 m (14 ft) in height, 1.06 m (3.5 ft) in width and 2.74 m (9 ft) in length. The stand was to promote isolation of the L.V. System from the vibrations of the wind tunnel.

The motor-actuated platform (fig. 4), capable of traversing 0.71 m (28 in.) along the wind tunnel axis and 0.9 m (36 in.) in the vertical axis, is fixed to the stand. D.C. motors with encoders position the table to an accuracy of 0.05 mm (0.002 in.). Dual controls allow operation of the platform from the balance chamber or the wind tunnel control room.

The base for the environmental isolation system is attached direct to the platform. It consists of a base plate 2.54 m (100 in.) by 0.96 m (38 in.) fabricated from 3.2 mm (1/8 in.) aluminum sheet. The plate has water cooling lines of 9.5 mm (3/8 in.), copper tubing attached to the top and 31.75 mm (1-1/4 in.) double lead sheet and foam insulation fastened to the bottom. This acoustical foam provides noise suppression as well as thermal insulation.

Bolted to the top of the plate are eight vibration isolation mountings (fig. 5) rated for 54.5 kg (120 lb) each. Two 25.4 mm x 76.2 mm (1x3 in.) aluminum rails traverse the mountings and provide a bearing surface for the optical bench. Also affixed to the plate is a 0.46 m x 0.61 m (18x24 in.) bulkhead panel for mechanical and electrical connections.

The optical bench (fig. 6) is a lightweight honeycomb structure with threaded holes on 50.8 mm (2 in.) centers on the top surface for mounting the optical components. The bench was cut to measure 0.86 m x 2.44 m (34x96 in.).

The environmental isolation cover is a five-sided box of 3.2 mm (1/8 in.) aluminum construction measuring 0.96 m x 1.02 m x 2.54 m (38x40x100 in.) with 9.5 mm (3/8 in.) copper cooling lines affixed to all five internal surfaces. The exterior is covered with the same 31.75 mm (1-1/4 in.) foam and lead insulation as the bottom plate. The beam exits through a 0.23 m (9 in.) diameter schlieren quality window. The cover assembly (fig. 7) fits over the optics bench with 13 mm (1/2 in.) clearance on all sides and rests on a foam rubber gasket attached to the base plate. A 25.4 mm (1 in.) diameter hole in

the cover provides for pressure equalization and a vent for the dry nitrogen purge used to prevent moisture condensation on the optics.

The four beam on axis backscatter optics system (fig. 8) is raised to a centerline height of 0.41 m (16 in.) by individual platforms and an elevated optical sub table. This height was dictated by the 0.41 m (16 in.) diameter corner mirror and its mount. A 15 watt Argon ion laser, enclosed in a pressure vessel, supplies light of wavelengths 488 nm (blue) and 514.5 nm (green). The vessel is constructed of 6.35 mm (1/4 in.) aluminum plate and rated for 34.5 K Pad (5 psid). A quartz window 25.4 mm (1 in.) diameter provides the pressure seal at the beam exit.

The laser beam passes first through a beam waist adjuster, an attenuator and then to a dispersion prism. This prism separates the beam by wavelength into 4 blue and 2 green beams. The separated beams are reflected on the first corner mirror and continue to diverge as they traverse the table. The green (514.5 nm) and the blue (488 nm) beams are reflected (individually) on the second and third corner mirrors and directed into the transmitting optics where each color is split into two beams of equal intensity. Final alignment adjustments are provided by the beam steering modules to insure coincident beam crossing. The beams exit the optics through the beam displacer that adjusts the beam spacing to allow passage through the zoom lens assembly.

The zoom lens assembly (fig. 8), fabricated to NASA specifications, allows the positioning of the beams over a range of 1.0 m to 4.0 m (3 to 12 ft) normal to the tunnel axis. The beams are reflected into the tunnel by a 0.41 m (16 in.) diameter corner mirror. This mirror on a 2-axis gimble mount provides additional beam positioning capabilities.

Light scattered from a particle passing through the measuring volume of each color is transmitted to the zoom lens by the large corner mirror. The zoom lens focuses the light onto color separating mirrors in the receiving optics system. The photo multiplier tubes (one for green, one for blue) take this light and produce electrical impulses. The photo multiplier outputs are amplified and sent to the processing equipment located in the control room (fig. 9). The processor consists of two identical module sets, one set for each color. Each module set contains a Front End Detector unit and a Logic Output and Display Module.

The Front End Detector receives the signal, strips it of any D.C. and amplifies the A.C. signal. The amplified A.C. is routed to the overload detector and through individual selectable high and low pass filter networks. The filters are adjustable from 0.5 to 32 MHz in multiples of 2. The filtered signal is then subjected to the threshold test. Both threshold and overload levels are manually set by the operator. Signal strengths that fall between the threshold and overload levels are accepted for further processing. Signals that fail to exceed the threshold or are in excess of the overload level are rejected. The instrument then resets and begins to process the next data event.

The multilevel sequencing circuit converts the acceptable analog data signal to a pulse train at digital voltage level of the same frequency as the analog data. This pulse train is sent to the Logic Display and Output module which performs a 5, 8 check. That is, the time required to collect five (5)

pulses is compared to the time required to collect eight (8) pulses divided by 5/8. If they fall within the desired accuracy as preset by the operator (0 to 6.25 percent in 10 steps) on the front panel, the 8 count time is used to calculate a frequency and sent to the data computer. The option exists to disregard this 5, 8 check and send all frequencies based on eight pulses to the computer. If data exceeds the accuracy selected, a reset occurs and the system discards the data sample. Upon completion of either an accepted data point or a rejection, the processor immediately will begin processing the next data event.

The position of the propeller (in degrees of rotation) is determined by an angle clock and recorded with each processed data sample.

The frequency of the fringe crossing and the propeller positions are fed to 4 direct memory access ports (DMA) (2 for each color) in the computer. Up to 4000 data points and their respective propeller positions from each channel can be stored in the DMA and used for on-line graphic display. The raw data can be placed on permanent disk storage for further analysis. Also recorded onto disk storage are the parameters set on the signal processing equipment, the data rate, the mean frequency, standard deviation, and the positions of the 2 axis table and zoom lens.

The computer also provides the interface for control of the equipment. By using the computer console, the table and zoom lens position, parameters of the signal processor, initiation of data acquisition, and graphics output can be controlled. The system can also be used for off-line data reduction by retrieving raw data from disk storage.

Figure 10 shows typical L.V. raw data graphical outputs taken during test operations on an 8 blade high speed propeller model.

SEEDING

Artificial seeding of the tunnel is accomplished through the use of 2 commercial atomizer units designed for L.V. applications. Diocetyl phthalate (D.O.P.) was used as the seeding material as recommended by the atomizer manufacturer. Each unit has 6 atomizers; any or all can be selected for use. The seed is discharged through four 25.4 mm (1 in.) diameter tubes located at various locations on the flow straightener in the tunnel bellmouth. The tubes are 6.1 m (20 ft) from the seeding cabinet (fig. 11) to the flow straightener. The model is located 18.3 m (60 ft) downstream of the seeding tube exits. The seed cloud with all 12 atomizers and all 4 tubes active is approximately 0.2 m (8 in.) high and 0.46 m (18 in.) wide at the model. Two tubes are assigned to each atomizing unit and are selected by operating valves.

Our data indicates particles to be 5.0 microns or less in diameter, with sufficient density to yield data rates of 2000-4000 counts per second in a freestream velocity of $M = 0.8$. Presently there is a significant reduction of data rate between the blades.

EVOLUTION OF THE SYSTEM

The operational environment of the 8x6 Foot Supersonic Wind Tunnel provided the greatest detriment to successful laser velocimetry measurements. The test section is contained in a domed structure called the balance chamber, which also houses the laser system and beam positioning controllers. During tunnel operations, the entire structure is subject to reduced atmospheric pressures, elevated temperatures, severe vibrations, and high acoustic pressures loadings. In addition, bleed holes in the tunnel walls used for boundary layer control cause turbulent air currents within the balance chamber.

The initial configuration (fig. 12) was installed with a compact 2 color 3 beam optics package in late 1979. The system could be aligned and operated satisfactorily using a small air jet to simulate tunnel air flow; however, it failed to function when the wind tunnel was in operation. It was discovered that the laser output power decreased as the balance chamber static pressure was reduced. When the tunnel reached the desired operating speed ($M = 0.8$), pressure had decreased by 34.5 kPa (5 psi) and the laser had no output at all. The loss in power was caused by the change in air density and the subsequent change in optical path length between the tuning mirrors of the Lasing cavity. This problem was eliminated by mounting the laser in a pressure vessel, as described earlier, maintained at atmospheric pressure.

With the laser power now thought to be stabilized, tunnel testing was resumed; however, L.V. signals were still unattainable. Post operation inspection of the optics system showed serious misalignment. It was theorized that the temperature increase of 28°C (50°F) in the balance chamber was causing the optical components to shift. A large water-cooled cover was constructed and rested directly on the optical bench. Thermocouples were installed and several tunnel runs were made. Laser data was successfully attained; however, it was of marginal quality and signals were no longer obtainable after 1 or 2 hours of operation.

Misalignment was found in post run analysis of the optics system; the suspected cause was vibration. The laser structure and balance chamber was fully instrumented with accelerometers and pressure transducers to confirm these suspicions. The results from this instrumentation showed that at tunnel operational velocity of $M = 0.8$, vibrations having peaks at 840, 3100 and 4000 Hz 4G amplitude were predominant on the optics table. The lowest frequency correlated with vibrations at the base of the laser support structure and results from the tunnel compressor drive system. The higher frequencies coincided with the acoustic pressures. An Overall Sound Pressure Level (OASPL) of 155 db at 3000 to 4000 Hz was recorded. The random high intensity peaks seen on the accelerometers were caused by the air exiting through the bleed holes and impinging on the laser cover.

A deflector shield was installed on the outside tunnel wall to protect the laser system from the bleed hole buffeting (see fig. 13). Data taken during tunnel runs at $M = 0.8$ showed vibration levels were reduced by 50 percent, resulting in a marked improvement in L.V. stability. However, the system did not meet our requirements.

After a restudy of environmental data, it was concluded that the optical table was bending due to the 16° to 22°C (30° to 40°F) temperature

differential from the top to bottom caused by the cooling box. This was remedied by placing the table on a water-cooled aluminum plate.

The poor signal quality noted earlier resulted in an electrical noise survey. This revealed high frequency noise was present; it was generated by the D.C. motor controllers, and an unknown source (existed even with all electrical equipment in the area turned off). In an effort to improve the unamplified signal, all signal cables were rerouted to increase the separation from the power cables. All power and control cables were shielded by an external braid in addition to existing cable shields.

The D.C. motors controllers were enclosed in a 3 sided Mu metal container (top, sides, and back), front and bottom were 3.2 mm (1/8 in.) aluminum sheet. This improved the signal quality during run condition by about 30 percent.

With the improvement of the signals, further runs were made and data analyzed; this data showed a wide variation in quality. This was traced to a periodic fluctuation in the laser power output. The laser can be operated in two control modes: light and current. Light mode keeps the light power output constant while current mode keeps the input current constant. Vibration of the components in the power output sensor (a photodiode and beam-splitting prism) used to control the laser power in the light mode was the cause of the fluctuations. The alternate control, current mode, was tried and displayed none of the modulations. However, remote operation of laser power was not available in the current mode. The feedback circuitry of the light control mode was modified to damp the oscillations. In addition, provisions were incorporated to allow remote switching from light mode to a preset power level in the current mode.

Further operations of the system yielded data of acceptable quality but the reliability of the system fell below requirements. Loss of alignment after only several hours of operation along with the tedious and time consuming set up (8 manhours) with this system indicated major design changes were in order. The redesign of the optics mounting and environmental isolation systems were initiated. This yielded the system described in the system description. Concurrently, efforts were made to stiffen the adjustments and make modifications to the optics package itself. In addition, an evaluation of alternative optics systems was begun.

The new environmental control system was installed, tested and met our requirements. Temperatures and vibrations were controlled to levels thought to be adequate for the system's reliable operation. The modified three beam system, however, continued to exhibit unsatisfactory performance.

The 4 beam optics were purchased and installed in late 1980. This system virtually eliminated all the problems encountered with the previous system. Set up time was reduced 80 percent while reliability increased to almost 100 percent.

SEEDING EXPERIMENT

Experiments in seeding the wind tunnel were conducted simultaneously with the work described above.

Many different seeding methods and materials were evaluated before deciding on the units described in the system description. Because of the possibility of solid airborne particles entering the bearings of the turbo propeller test model, the use of a fluidized bed to seed the tunnel was prohibited. Therefore, our efforts focused on liquid particles generated by atomizers.

Several systems were evaluated using actual tunnel runs. L.V. data was taken along the stagnation streamline of a blunt nose model over a range of velocities.

Ultrasonic nozzles, airline oil misters and various atomizers were evaluated with liquids such as dioctyl phthalate, glycerine, silicon, mineral, penetrating and hydraulic oils. Various impactors and settling tanks were tried in an effort to segregate the particles' sizes. Evaporation techniques were also tried by adding solvents to the oils. The techniques generally yielded particles in the range of 8.0 microns to 20.0 microns which were considered too large for the expected velocity gradients. The units presently installed were the best of the systems tested. The indicated seed diameters were less than 5 microns. The manufacturer's literature states that the predominant size is 2 microns.

The location and number of seed injection tubes were determined experimentally. Two atomizer units each supplying two 25.4 mm (1 in.) diameter injection tubes mounted on the wind tunnel flow straightener provide a seed cloud of approximately 0.2 m x 0.46 m (8 by 24 in.) at the model.

SUMMARY

A Laser Velocimeter has been used to make non-intrusive measurements of velocity in front, behind and in between the blades of a spinning 8 bladed propeller model operating at $M = 0.8$ at Lewis Research Center's 8x6 Foot Supersonic Wind Tunnel.

The adaptation of a delicate instrument such as an L.V. to a large wind tunnel necessitated the isolation of the instrument from the environment generated by wind tunnel operation. The steps taken to control heat, vibration, pressure variations and electrical noise are detailed in this report.

CONCLUDING REMARKS

A Laser Velocimeter has been successfully operated in a large scale high speed wind tunnel. This report discussed how the system had to be redesigned as solutions to one problem unmasked other problems. The environment was hostile in that it included low pressure, high vibrations, high acoustic pressures, high temperatures and high electrical noise. Less complicated optics were utilized to stabilize the optical light path. In the final

analysis, the critical criteria for successful operations were isolation of the system from the environment and the selection of more stable optics.

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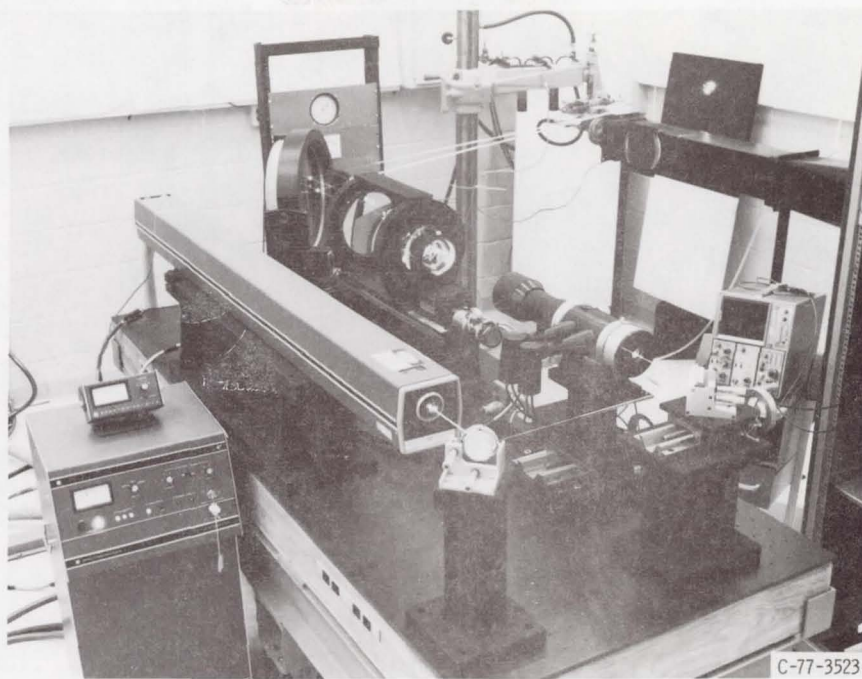


Figure 1. - Laser system in checkout area.

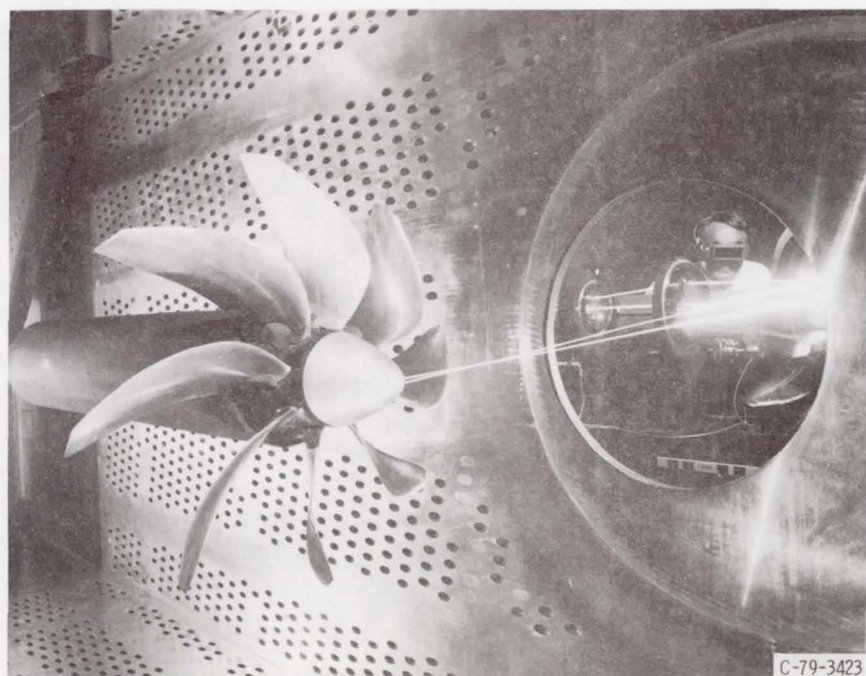
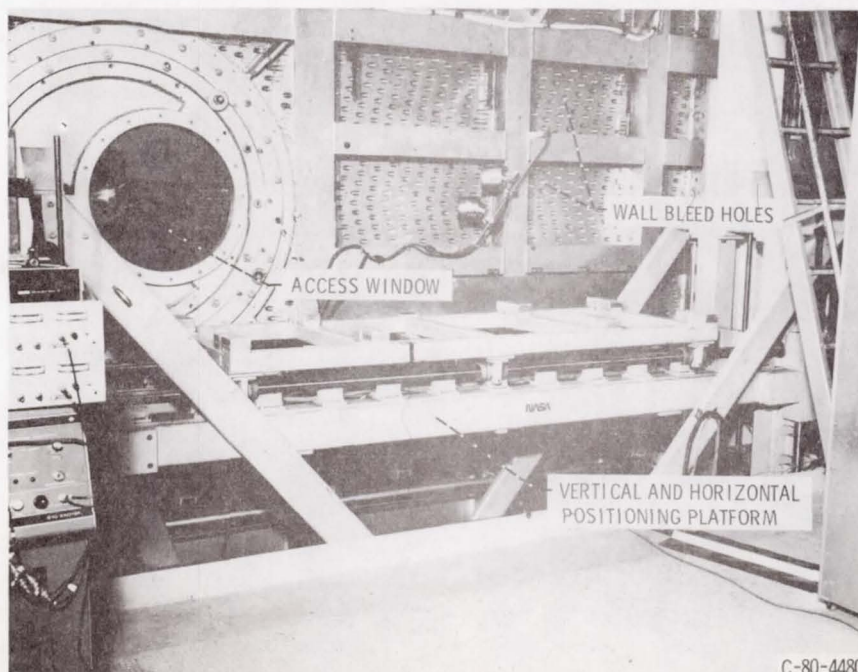


Figure 2. - Truboprop model in 8x6 wind tunnel.



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Figure 3. - Laser support structure.



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Figure 4. - Two axis positioning platform.

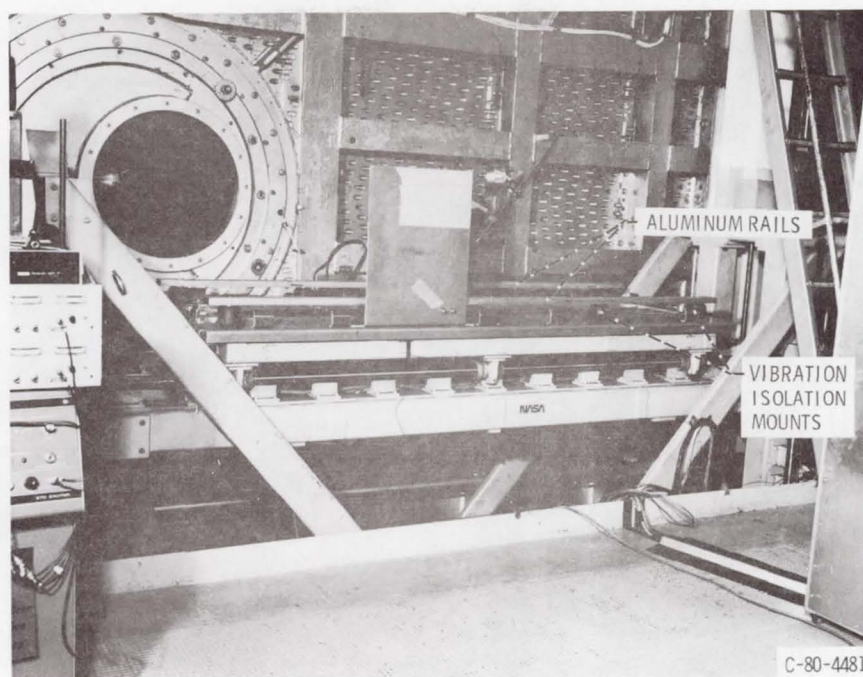


Figure 5. - Optics table isolation and support structure.

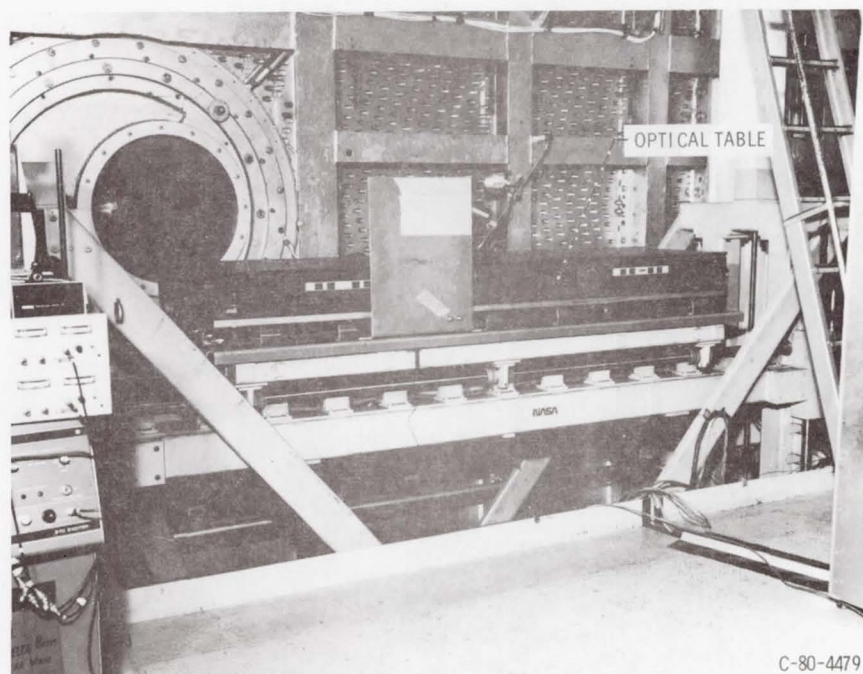


Figure 6. - Laser optical table installation.

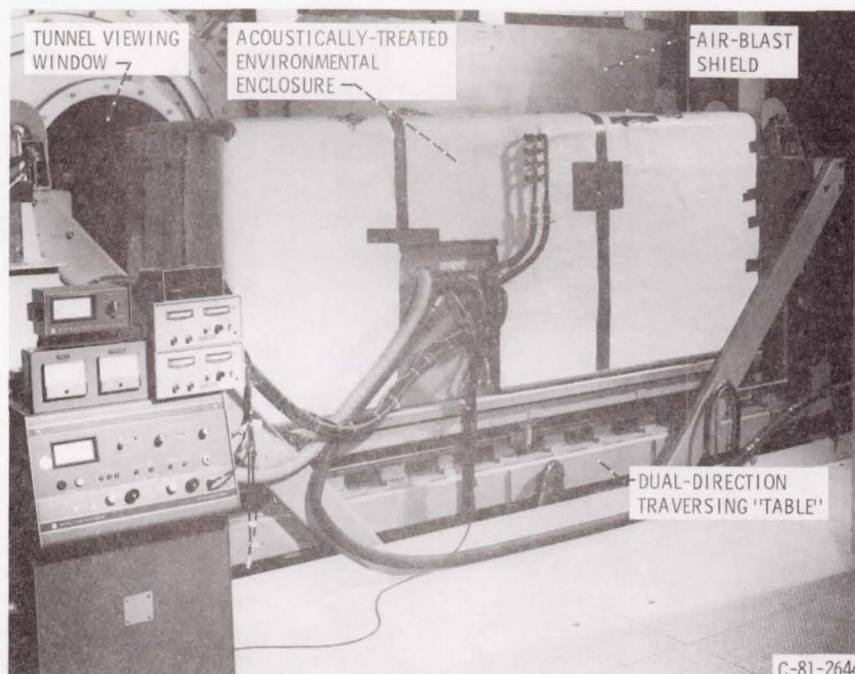


Figure 7. - Laser velocimeter system components covered with the environmental enclosure.

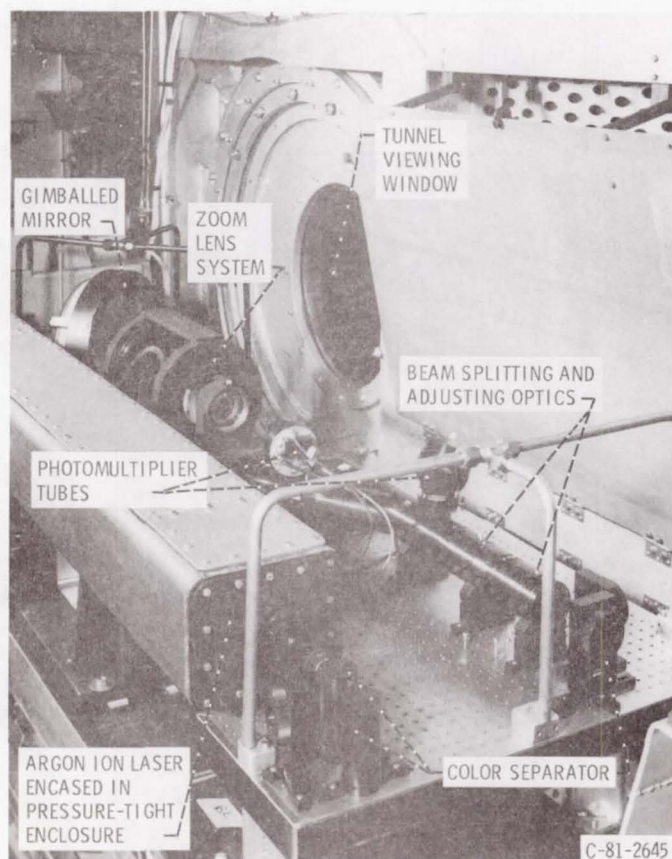


Figure 8. - Components of laser velocimeter system installed in 8-by 6-Foot NASA Lewis Supersonic Wind Tunnel.

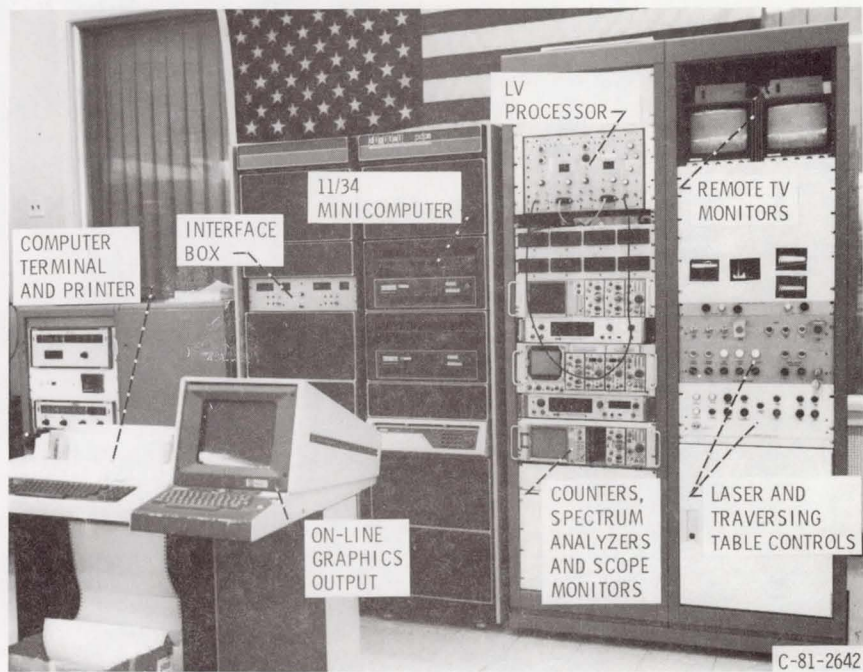


Figure 9. - Minicomputer, LV (laser velocimeter) processor and remote control and monitoring instrumentation of the LV system.

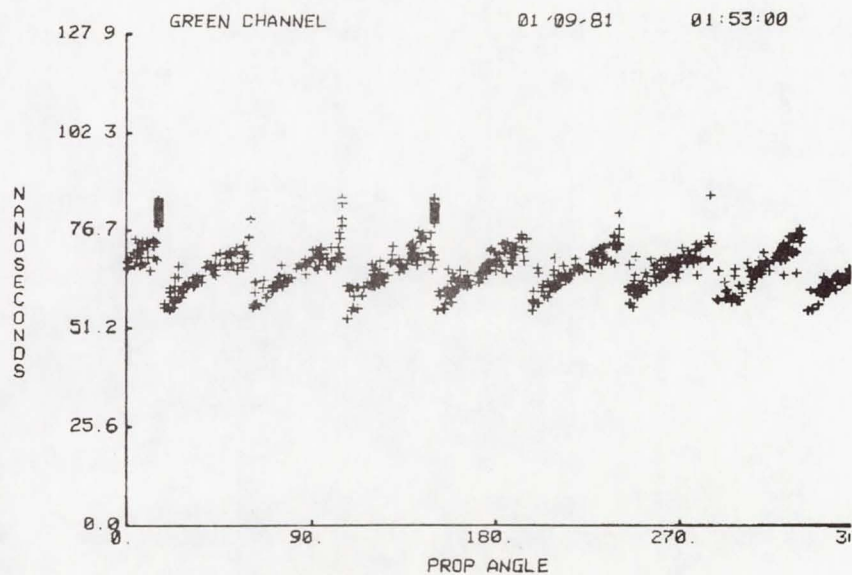


Figure 10. - Typical graphic display.

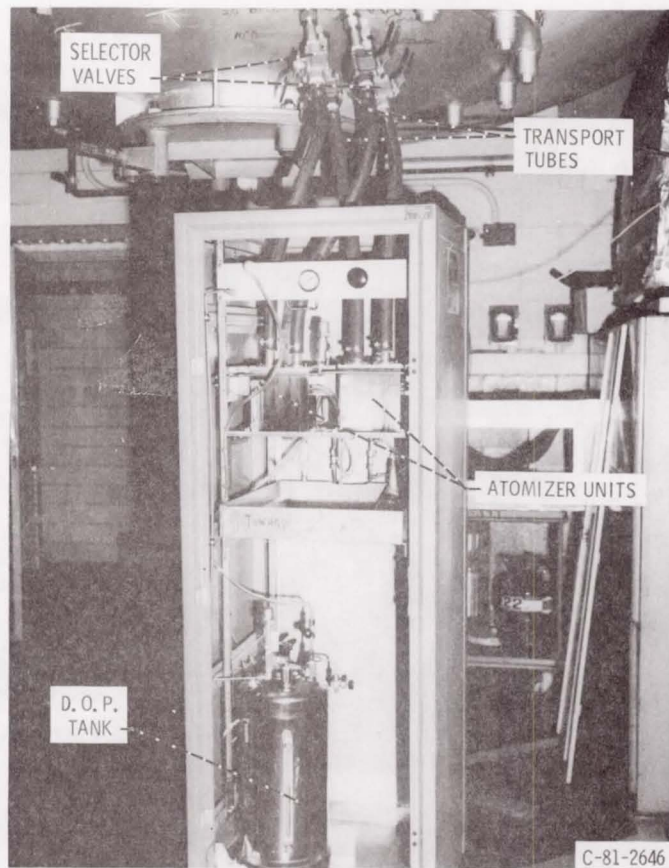


Figure 11. - Seed generator.

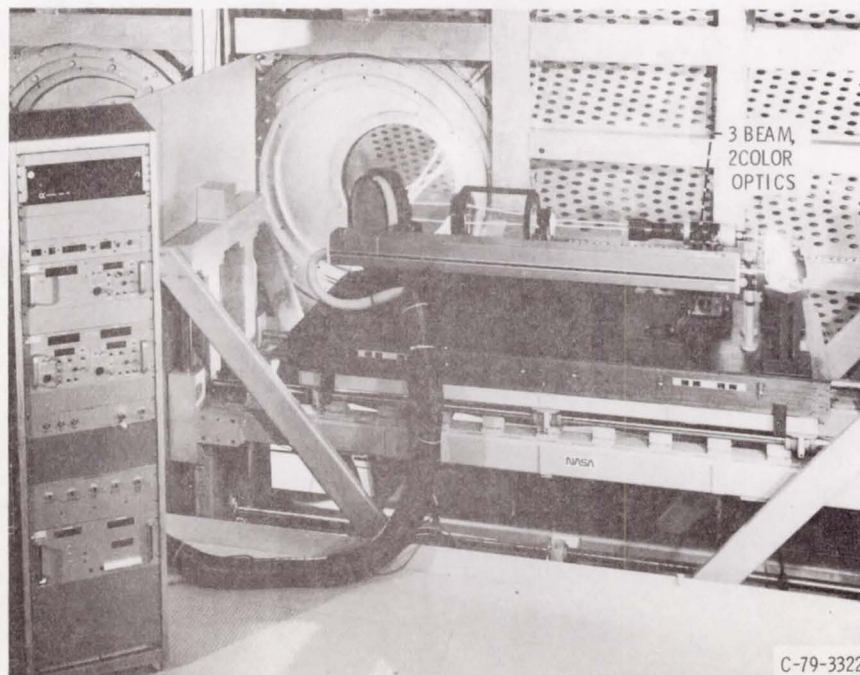
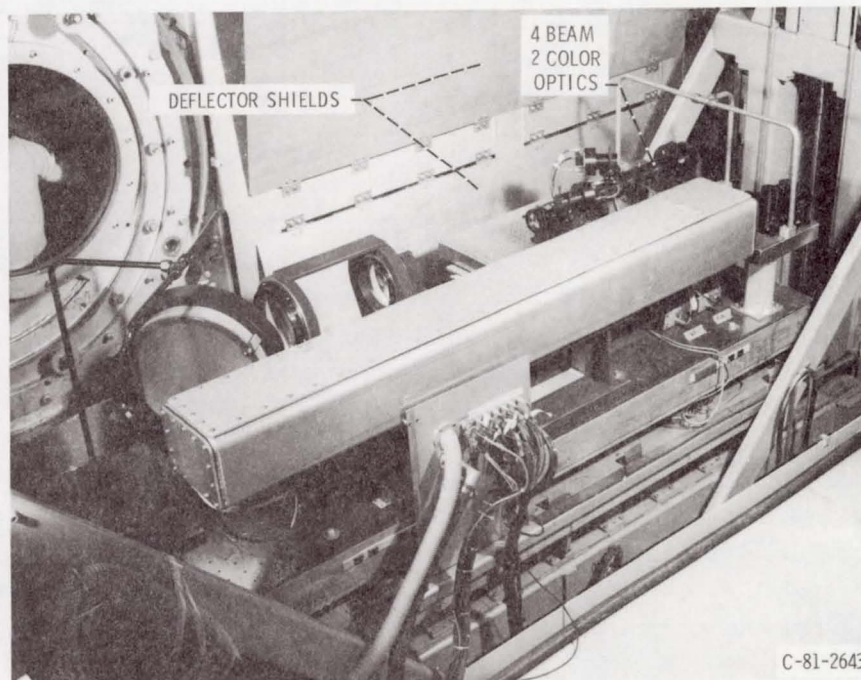


Figure 12. - Initial configuration.



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Figure 13. - Deflector shield installation.

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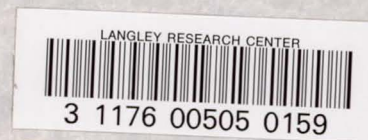
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